Rocky Mountains
Southwest
Great Plains

Research Note RM-500

September 1990

USDA Forest Service
Rocky Mountain Forest and Range Experiment Station

Comparison of Moisture Retention Curves for Representative Basaltic and Sedimentary Soils in Arizona Prepared by Two Methods

L. J. Heidmann,[1] Michael G. Harrington,[2] and Rudy M. King[1]

Abstract

Moisture retention curves were prepared for representative basaltic (silty clay loam) and sedimentary (sandy loam) soils in Arizona by two methods. With the vapor pressure method, small soil samples come into equilibrium moisture content with saturated salt solutions of known water potential. The other method measured the water potential of soil samples directly using thermocouple psychrometers. Both methods produced similar curves for the fine-textured basalt soil. However, the curves for the coarse-textured sedimentary soil were unequal. The vapor pressure method, the simplest, least expensive method for developing moisture retention curves, was reliable only for the fine-textured soil.

Keywords: Moisture retention curves, thermocouple psychrometer, vapor pressure, basalt soil, sedimentary soil

The evaluation of soil moisture in forestry research and general management practices frequently takes the form of quantitative measurements such as percent by weight or volume, or depth estimations. Another characteristic of soil moisture is water potential (ψ), which is the energy or tension that must be overcome to remove the water, whether by plants or through evaporation. Therefore, soil water potential (ψs) appears to be a better classification where plant response is of concern because, unlike quantitative categorization, the values are directly comparable regardless of soil characteristics.

Capabilities exist for evaluating ψ in situ by thermocouple psychrometry (Rawlins and Campbell 1986), by tensiometry (Cassel and Klute 1986), and by electrical resistance (Campbell and Gee 1986). An alternative is to develop soil moisture retention curves (also known as drying curves, desorption curves, or moisture release curves) for individual soil types. These curves plot soil moisture content (SMC) against ψs so a conversion of the easily measured SMC can be made.

In the laboratory, soil moisture retention curves can be developed by measuring SMC gravimetrically and plotting these values against ψs determined by thermocouple psychrometers, pressure membranes, tensiometers, or by allowing soil samples to equilibrate with the vapor pressure of salt solutions of known ψ (Klute 1986). Advantages and disadvantages exist for each method. Thermocouple psychrometers are quite precise within the –0.1 to –8.0 MPa range and results are obtained rapidly. However, the equipment is expensive and sensitive. Pressure membranes and tensiometers are less expensive, but the most commonly available units measure ψs only down to –1.5 MPa and –0.1 MPa, respectively. With the vapor pressure method, a wide range of ψs can be determined by using a series of inexpensive salt solutions; however, several weeks are required for soil samples to reach equilibrium.

[1] *Plant Physiologist and Biometrician, respectively, with the Rocky Mountain Forest and Range Experiment Station. Headquarters is in Fort Collins, in cooperation with Colorado State University. Research reported here was conducted at the Station's Research Work Unit at Flagstaff, in cooperation with Northern Arizona University.*

[2] *Research Forester with the USDA Forest Service, Intermountain Research Station, Missoula, Montana.*

As part of a comprehensive study of the water relations of southwestern ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) seedlings under drought conditions, moisture retention curves were developed for the two major forest soil types in Arizona. Curves were generated with data from thermocouple psychrometers and from the vapor pressure method, and both were supplemented at the higher ψ with data from the pressure membrane. The pressure membrane measures soil matrix potential while the psychrometer and vapor pressure methods determine total ψs. Richards and Ogata (cited by Richards 1965) have shown that vapor pressure and pressure membrane measurements are in close agreement. Klute (1986) also indicates that if the osmotic component of water potential is negligible then the pressure membrane and thermocouple psychrometer give similar results. This paper discusses the methods used and compares the results in an attempt to recommend a simple, reliable method for developing moisture retention curves.

METHODS

Physical Soil Characteristic

Forest soils in the southwestern United States are primarily volcanic (derived from cinders or basalt rocks) or sedimentary (from sandstone or limestone) in origin. Textural characteristics for each broad soil type are similar over a wide geographical area (Heidmann 1975). Sedimentary soil (sandy loam classified as a Typic Eutroboralf) was collected from the top 15 to 20 cm on the Long Valley Experimental Forest, 96 km south of Flagstaff, AZ, at an elevation of 2195 m. Basalt soil (silty clay loam, a Typic Argiboroll) was collected from the same depth on the Fort Valley Experimental Forest 16 km northwest of Flagstaff, at an elevation of 2134 m. Soils were air-dried for several days then were passed through a 2-mm soil sieve. Soil bulk densities were determined by the sand cone method (Blake and Hartge 1986) and soil textures by the hydrometer method after organic matter had been removed by burning (Gee and Bauder 1986).

Moisture Retention Curves

Equilibrium Vapor Pressure

Moisture retention curves were prepared by determining SMC at ψ –0.6 to –7.66 MPa by allowing soil samples to come into equilibrium with solutions of known ψ. Salt solutions with a range of ψ were prepared according to Spencer (1926), Hodgman (1962), and Greenspan (1977). These calculated ψ were checked with a thermocouple psychrometer.

After the solutions were prepared with distilled water, 400-ml samples were placed into separate glass desiccator jars. Four small, shallow, metal soil cans containing 5 g of moist soil were then placed on perforated ceramic plates suspended over the solutions in each jar. A partial vacuum was applied to the jars, which were placed in a growth chamber and kept at 20°C in constant darkness. After 2 weeks, the soil samples were removed from the jars and were weighed to the nearest 0.1 mg on an analytical balance. Samples were replaced in the jars and placed back in the growth chamber under vacuum. Thereafter, samples were weighed weekly until the change in weight was 5 mg or less.

Thermocouple Psychrometer Method

Thermocouple psychrometers estimate ψs by directly measuring the relative vapor pressure of the sample being tested. Screen-caged thermocouple psychrometers were used within stainless steel calibration chambers similar to those described by Brown and Bartos (1982). The psychrometers were previously calibrated using six KCl solutions with ψ ranging from –0.2 to –6.5 MPa. Linear regressions were developed for each psychrometer using ψ as the dependent variable and psychrometer output in microvolts as the independent variable. All regressions had $r^2 > 0.99$.

Development of moisture retention curves followed techniques described by Campbell et al. (1966). Tests were run for each of the two soil types. A series of 50-g, air-dry samples were moistened with distilled water in soil cans. Each sample was then allowed to dry for different periods of time. After specific drying had been achieved, each soil can was sealed and shaken intermittently until the sample became homogeneous. A portion of the sample was then placed into the calibration chamber surrounding the psychrometer, and the rest was used to gravimetrically determine SMC. The psychrometer chamber was sealed and placed into a water bath at 25°C. Water potential of the samples was measured after equilibrium was reached in the chamber, usually after 3 hours. After three measurements were taken at hourly intervals, a mean ψs was determined which corresponded to a specific SMC. A series of trials were run until a range in ψs was achieved from –0.1 to about –7.0 MPa. Pressure membrane data were used to supplement both methods in the wet region with SMC corresponding to ψs of 0.00, –0.03, and 0.25 MPa (Heth and Kramer 1985).

Analysis

The SMC/ψs relationships are generally power functions (Roundy 1983, Saxton et al. 1986). Specific functions for each soil were determined by regression analysis. Differences between models by methods were determined using the extra sums of square method (Draper and Smith 1981).

RESULTS AND DISCUSSION

A comparison of the physical characteristics of the two soils is shown in table 1. The coarse texture of the sedimentary soil is evidenced by its having nine times

Table 1.—Physical characteristics of basalt and sedimentary soils in Arizona (means of four samples and standard deviation(s)).

Characteristic	**Soil**			
	Sedimentary		**Basalt**	
	$\bar{x}$	**SD**	**$\bar{x}$**	**SD**
Bulk density, g/cm^3	1.74	0.40	1.18	0.03
Composition, %				
Sand	72.50	0.00	8.90	1.60
Silt	17.10	0.04	55.10	1.40
Clay	10.40	0.40	36.00	2.80
Organic matter	0.38	0.18	2.23	0.93

Table 2.—Comparison of soil moisture retention curves for two Arizona soils developed by two methods.

Basalt soil

Vapor pressure method:

Water potential (–MPa) = $281996.64/\mathrm{SMC}^{4.989}$

R^2 = 0.95, Standard error of estimate = 0.55

Thermocouple psychrometer method:

Water potential (–MPa) = $61466.84/(\mathrm{SMC})^{4.359}$

R^2 = 0.99, Standard error of estimate = 0.16

Method comparison:

$F_{2,\ 50}$ = 11.97 ($p < 0.001$)

Sedimentary soil

Vapor pressure method:

Water potential (–MPa) = $9.13/(\mathrm{SMC})^{3.046}$

R^2 = 0.80, Standard error of estimate = 1.12

Thermocouple psychrometer method:

Water potential (–MPa) = $9.45/(\mathrm{SMC})^{4.659}$

R^2 = 0.96, Standard error of estimate = 0.35

Method comparison:

$F_{2,\ 63}$ = 11.16 ($p < 0.001$)

the sand and one-third as much silt and clay as the basalt soil. Soil moisture contents at saturation for the sedimentary and basalt soils are 25.4% and 47.7% by weight, respectively, and at field capacity (–0.03 MPa) are 9.9% and 35.4% by weight, respectively.

The nonlinear regressions developed for both soils by both methods are typical of moisture retention curves (Campbell et al. 1966) and are shown in figure 1. Our curves resemble those prepared by Pharis (1966), who determined lethal points for several conifers grown in "builders sand" and Glade pumice soil. The inflection point of our sedimentary soil is about 1.5% lower than that of Pharis' curve for "builders sand," but otherwise the curves are similar.

The shapes of the soil moisture retention curves are quite similar for most soils, i.e., ψs stays at a high level (low negative value) until SMC reaches a critical point (inflection point) then with a slight drop in SMC, ψs drops dramatically. There is some variation in steepness of curves as well as in inflection points, depending on soil type. For our two soils, curves prepared using the vapor pressure method are visually similar to those prepared using thermocouple psychrometers (fig. 1). The regression equations are statistically different between methods, however (table 2). The primary reason for statistical differences is that, in specific regions of the curves, there are substantial vertical differences at particular soil moisture values.

Even though statistical differences are indicated, it may be of interest to see where the differences specifically exist. For the basalt soil, the regressions are very similar at the wetter soil moisture and, in fact, converge at about 11% moisture content (–1.8% MPa). Divergence slowly increases as the soil dries further, but is probably not biologically significant until moisture drops below 10% where corresponding water potential differences increase beyond 0.2 MPa. At this level of soil dryness (< 3.0 MPa), moisture is certainly limiting plant processes and is nearing an unavailable status. Therefore, if the curves developed by the two methods are biologically

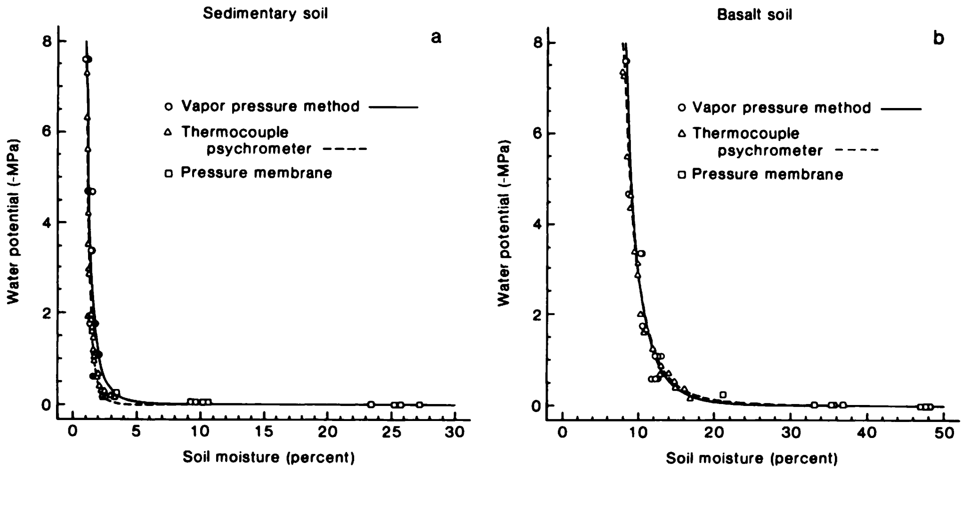

Figure 1.—Soil moisture retention curves prepared by using the vapor pressure and thermocouple psychrometer methods and supplemented by pressure membrane data: (a) sedimentary soil; (b) basalt soil.